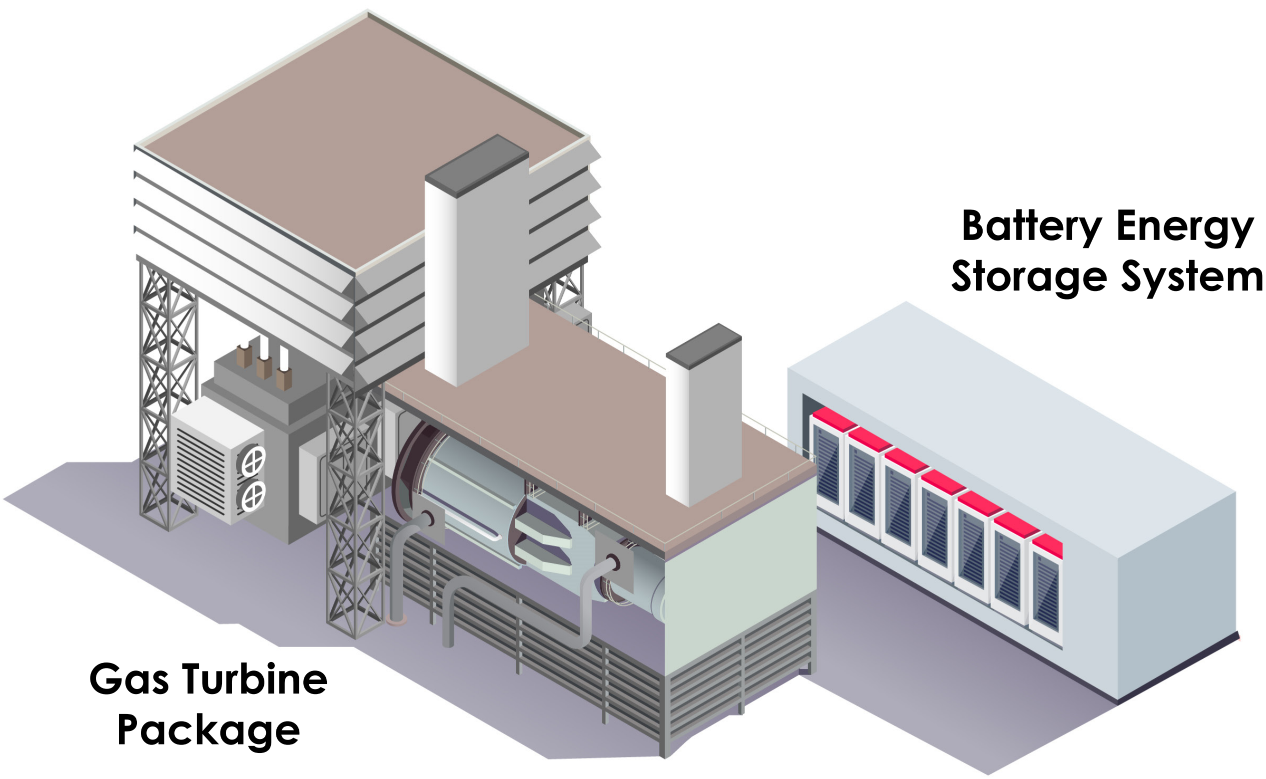
HYBRIDIZED GAS TURBINE (GT) PLUS BATTERY ENERGY STORAGE SYSTEMS (BESS): TECHNOLOGY BENEFITS AND APPLICATION BARRIERS

Gas Turbine + Battery + Hybrid System Controller =
Hybrid Gas Turbine (Hybrid GT + BESS)



August 2021

Executive Summary

As the grid needs continue to evolve with increasing regulatory mandates for reducing CO_2 emissions and greater variable renewable energy penetration, generators are being required to provide flexible operations while reducing the impact on emissions, O&M, and availability. To meet these needs, power producers are evaluating hybrid gas turbine plus battery energy storage plants. Hybridizing gas turbine plants by adding battery energy storage combines the battery's flexibility and responsiveness with the gas turbine's ability to provide sustained energy.

Hybrid gas turbines and energy storage offers distinct operational characteristics, including:

- Lower plant costs--> lower cost to provide services --> lower cost to rate payers
- Optimized GT operation (lower fuel usage) --> lower GHG and emissions
- Improved grid stability for isolated/islanded systems
- Black start with reduced emissions
- Increased grid resiliency, the ability to respond to events that can disrupt supply on a system-wide basis, and
- An answer to the growing utility challenge - plenty of capacity, but not the right kind of capacity

This white paper seeks to identify potential value streams of co-locating and integrating battery storage at a gas turbine facility and barriers that may prevent the system from maximizing its value. While hybrid energy systems like solar plus battery energy storage are becoming increasingly popular, hybrid gas turbine plus battery storage (Hybrid GT+BESS) deployment has been relatively limited.

However, it is important to note that Hybrid GT+BESS technology is commercially available with significant and successful operating experience in the CAISO & AESO markets.

The aim of this white paper is to inform decision making on hybrid gas turbine plus energy storage system deployment and market development by providing an overview of hybrid system characteristics, the value proposition, and the barriers to fully realizing those benefits. With this perspective, the very large fleet of existing gas turbines worldwide can be better utilized (re-purposed) for the evolving grid changes needed to adapt to growing renewable capacity and reduced GHG emission targets.

Background

What is a Hybrid System?

There are varying definitions across the industry, including independent system operator (ISO)[1] market rules, of what constitutes a hybrid system. Many of the ISO definitions specify that the resource is being offered, operated, or modeled as a single resource, a specific coupling configuration, or specific resource type combination. EPRI has a broader definition of hybrids *as a resource facility consisting of multiple co-located assets comprising of multiple technologies that can potentially inject and/or withdraw energy whereas the operation of either or both technologies has interdependencies (physical or otherwise) between the technologies*.[2] This definition allows for organized market participation models for the technology type, configurations and resource combinations, and even the possibility, if desired and found acceptable by both ISO and hybrid asset owners, for the participation model to change throughout the life of the plant or even within a day. This paper focuses on hybridized gas turbine plus battery storage systems referred to as Hybrid GT+BESS systems operating as a single resource, unless stated otherwise.

What is a Hybrid GT+BESS System?

Batteries are the common technology for promoting the hybridization of electricity production resources since they are scalable and modular and can therefore be installed in all parts of the electricity network and in particular in existing power plants where generation assets are already available.

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This white paper was prepared by EPRI.

[1] In this paper ISO is used interchangeably with regional transmission organization (RTO) and transmission system operator (TSO) as an entity responsible for coordinating and controlling a portion of the electric grid.
[2] *Electricity Market Integration of Energy Storage and Hybrid Storage-Plus-Renewables Technologies: 2019 Update*. EPRI, Palo Alto, CA: 2020. 3002016759.

Hybridizing gas turbine plants by adding battery energy storage combines the battery's flexibility and responsiveness with the gas turbine's ability to provide sustained energy. Hybrid GT+BESS plants offer enhanced performance characteristics over standalone gas turbine plants. The batteries' ability to respond fast to changes in the grid provides added flexibility to the gas turbine operation.

On a system with relatively unconstrained transmission, a battery and a gas turbine placed separately on the system may provide the same system-level benefits but could not take advantage of plant savings discussed in the following section. Additionally, these hybrid plant characteristics introduce new opportunities to participate in wholesale markets to support plant cost recovery.

While much of the Hybrid GT+BESS activity and operating experience has been with simple cycle aeroderivative GTs, there is also some experience and interest in hybridizing of the many large frame CCGT plants. In these cases, the battery system modifies the ramping ability, compensating for the inherent steam turbine's response lag. See Figure 2.

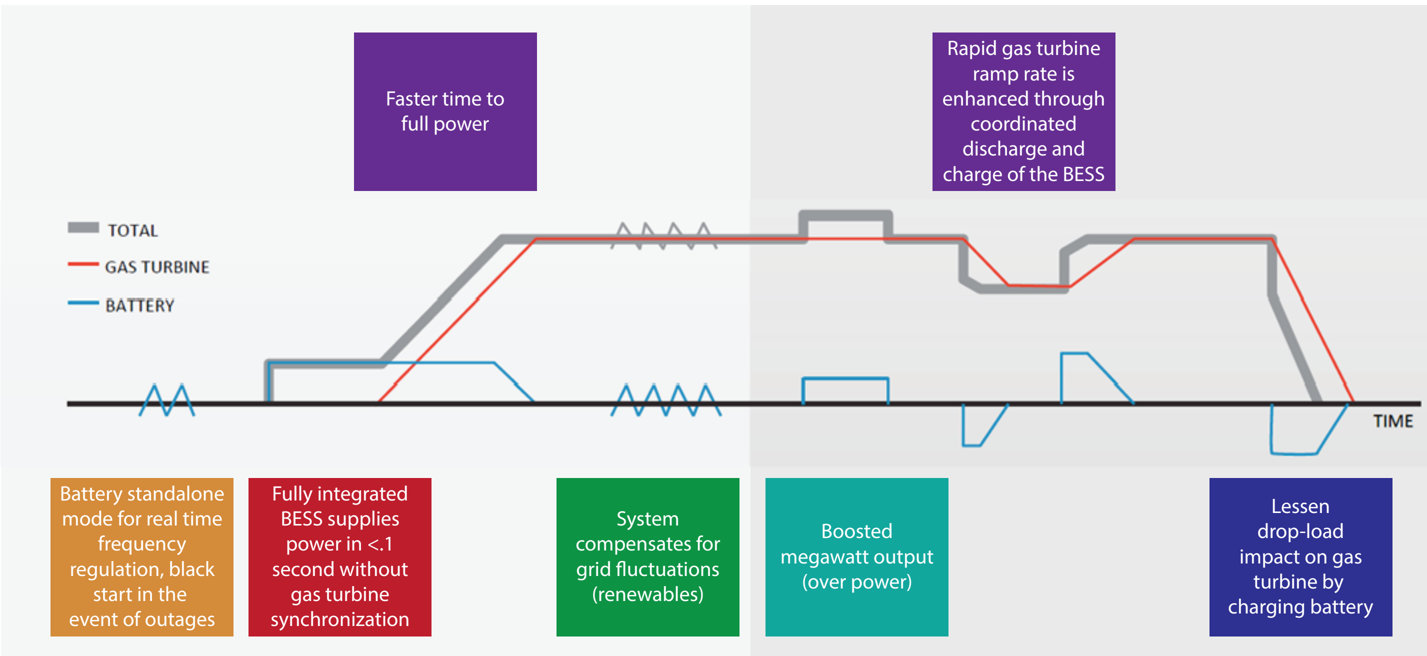


Figure 1. Optimized Gas Turbine and Battery Energy Storage System Operations - Image Copyright 2021, Mitsubishi Power Aero LLC, used with permission

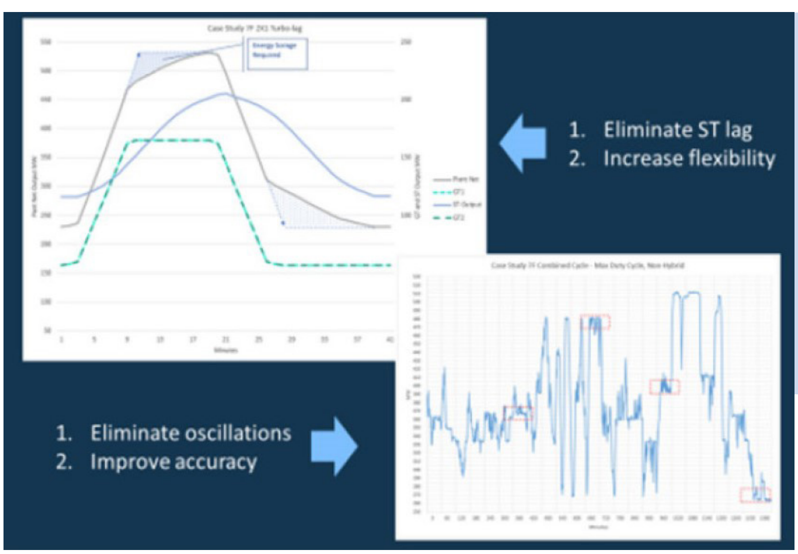


Figure 2. Hybrid Combined Cycle (CCGT) - In systems with high variable generation that are dependent on CCGT's as a base-loaded/ firming resource, increasing the CCGT ramp rate by eliminating the steam turbine lag can significantly reduce overall fuel burn. In most combined cycle applications, the gas-turbine is capable of ramping around 40MW/min, but due to the lag-time that it takes for the waste heat to be converted to steam, the overall cycle ramp is limited to just around 15MW/min. eliminating this lag-time by utilizing stored energy means that one CCGT can provide the ramping of 2 or 3 non-hybrid CCGT, allowing for units to be taken off-line during low demand periods. Copyright permission granted to EPRI by Wellhead Power Solutions, LLC.

Benefit Considerations

Standalone gas turbines have the ability to meet a variety of grid objectives; however, hybridizing with a BESS can potentially provide those services more efficiently with faster response to grid needs. The hybrid system can offer several services while the gas turbine is offline, opening new market participation opening new market opportunities. The system can also help to optimize plant performance.

Grid Services

Spinning reserve, non-spinning reserve. A Hybrid GT+BESS system can potentially provide enhanced tertiary reserve services. The available capacity for spinning reserve is the difference between the resource's maximum operating limit and its dispatch set point. Spinning reserve can only be provided by resources that are online and can respond immediately (i.e., the resource is immediately responsive to provide additional energy). A resource's capability for non-spinning reserve is limited by how much the resource can provide when starting up and synchronizing with the grid within a certain time frame (e.g., ten minutes). Therefore, although offline resources cannot immediately provide energy, they are qualified to provide non-spinning reserve as long as they can start and provide full response within the ten-minute time frame. Note that spinning reserve has a greater value to system operators since it provides energy immediately. Spinning reserve is typically provided by online thermal and hydro generation, whereas non-spin reserve is typically provided by offline gas turbines and hydro turbines since such technologies are able to startup in less than ten minutes. The addition of a battery to gas turbine may make the hybrid system competitive with the traditional technologies that provide spinning reserve. The hybrid system could provide spinning reserve with the gas turbine offline, where the battery would provide the instantaneous reserve until the generator ramped up to provide the remaining capacity for the reserve period. This approach avoids operating the gas turbine, and potential other thermal units, at an inefficient part load in order to provide the spinning reserve headroom.

Frequency response. For a generator to provide automatic frequency response through its governor droop control function, it must be online and operating at or above the plant minimum turndown (Pmin). A hybrid plant has the ability to provide this response with the battery while the gas turbine is offline (Pmin=0). The battery inverter can provide a faster response. ERCOT's Fast Frequency Responsive (FFR) reserve is an example of a market that compensates for the battery's fast response.

Regulation service. The hybrid system has ability to provide frequency regulation when the gas turbine is offline or online. When offline, the battery alone can provide the service, introducing a new market opportunity not available to a standalone gas turbine plant. When online, there is potential for the gas turbine to operate at a higher output and the battery to cover frequency regulation requirements. The hybrid system can also provide regulation in a much more accurate, faster ramping, manner, qualifying for fast frequency regulation markets, such as PJM's Regulation D.

Black start. Black start generators are the units which do not require off-site power to start. It is very common to use gas turbines as black start generators. Batteries have been deployed with aeroderivative and large frame gas turbine generator sets to start the gas unit. These units can usually be started using remote commands and can pick up load quickly. For larger gas turbines operating in a simple cycle mode, batteries have been deployed to replace the on-site diesel generators which are typically used to start the plant. Replacing diesel generators offers benefits of reduced emissions and reduced noise levels.

Flexibility. In areas with high renewable energy penetration, new market and grid services are emerging and being developed. An example of this is CAISO flexible ramping product and additional enhancements being considered for day-ahead markets. Hybrid systems can improve ramping speeds of standalone gas turbines to provide these services.

It is challenging to quantify the overall impact to the grid of optimized hybrid system operation because it is dependent on how the systems would be dispatched if scheduled separately or as a single asset. EPRI is currently conducting research and performing production cost model simulations to fully understand the hybrid benefits to grid operations.

Isolated/Islanded Systems

In isolated or islanded systems, the grid services described above may have increased value for maintaining system stability and reliability, especially in islands with high variable renewable energy resources. For example, sudden steep swings in wind energy can cause frequency deviations outside of normal operating limits, resulting in load shedding or wind curtailment that could be mitigated by a battery and by the battery plus gas turbine for sustained events. Where gas turbines make up a higher percentage of base load or load following generation, the battery provides added flexibility by

meeting regulation and reserve requirements and potentially allowing the system to operate with a reduced number of units and optimized operation of the units online. Freeing up gas turbine capacity through hybridization may also be a planning strategy. Batteries have a relatively short development timeline compared to deploying traditional generation. Therefore, adding batteries could provide incremental capacity to accommodate load growth and defer decisions on adding new generation to a later period.

Plant Cost Reduction and Derived Rate Payer Savings

As the cost of solar photovoltaic and batteries continue to decrease, solar plus storage hybrid systems are becoming competitive with gas turbines for providing peaking capacity. Hybridizing a gas turbine with battery energy storage has the potential to reduce the plant start-up and marginal operating costs, making the plant more competitive in the wholesale electricity market for proving capacity and ancillary services. This lower plant cost improves asset merit order, resulting in an overall lower cost to provide capacity to the grid which ultimately reduces cost to ratepayers.

Operation and maintenance cost savings include:

Fuel savings. With integrated controls, a hybrid system can optimize the plant dispatch to improve the efficiency of the gas turbine. For plants providing energy and ancillary services, a gas turbine does not always operate at its lowest heat rate if it also needs to provide spinning reserves or frequency response. If the battery is able to provide those ancillary services, it would allow the gas turbine to turn off or run at a lower, more efficient heat rate. Additionally, for plants providing contingency reserves, there may be reduced fuel consumption if the battery can be used to enable a normal start up sequence instead of a fast start.

Maintenance or overhaul savings. Reducing the number of starts, fast starts, or heavy cycling equates to reduced run time and extends time between major overhauls. This maintenance deferral is a maintenance saving. With an increasing amount of variable renewable generation, gas turbine may be cycled more frequently if they cannot turndown their load when demand decreases temporarily. The battery could be charged to keep load on the gas turbine when not needed by the grid.

Startup costs/Demand Charges. Gas turbines need an external source to start up the plant. This may be through diesel generator or using grid power. Using the battery of the hybrid system could result in reduced diesel generator use or grid demand charge savings. The battery may require charging when the gas turbine is not running and can be trickle charged from the grid to avoid increasing demand changes.

Shared plant staff. The ability to leverage operators or emergency services on-site can reduce costs compared to a standalone facility that may need a separate staff.

Additionally, there are installed cost savings from co-locating resources compared to standalone systems. These savings may include:

Shared interconnection infrastructure. The hybrid system uses shared infrastructure, including the switchyard, protection, control building, and other infrastructure that would be an additional cost for a new standalone system. Although there may be some equipment upgrades or modifications required, eliminating the need for a new substation can be significant cost savings.

Potential reduction in interconnection cost and/or schedule. Depending on the utility or balancing authority's interconnection rules and processes, installing battery energy storage at an existing gas turbine plant may have an option to fast track the interconnection study process. Modifying an existing agreement may have lower interconnection fees and a shorter study period. An accelerated schedule could result in financing savings and reduction in soft costs for supporting the interconnection process.

Utilize existing land and building infrastructure. Siting a battery energy storage system at an existing generation facility could reduce or eliminate the need for new environmental studies or permitting. Additional savings could result if land preparation is reduced and the negotiating or arranging of leasing contracts is not required.

Reduced sizing requirements. For some applications, the battery in a hybrid system can be sized smaller in power and energy capacity than a standalone battery providing the same service. For example, in the Southern California Edison Case Study (Appendix A) discussed later in this paper, a 10 MW, 4.3 MWh battery and 50 MW gas turbine can offer 50 MW of spinning reserve. Whereas as standalone battery would need to be sized for 50 MW, 50 MWh to offer the same amount of reserves.

Environmental Benefits

The optimized dispatch of Hybrid GT+BESS plants result in additional environmental benefits.

Reduced greenhouse gas emissions. Hybrid systems will have lower runtime hours for the gas turbine because the gas turbine can be offline for some services. Additionally, greenhouse gas reductions are achieved when gas turbines operate at a lower heat rate instead of less efficient part-load. Although it may be technically feasible to operate separate resources and separated sited systems in a similar way to optimized hybrid plants, in practice they are not likely to be dispatched that way if each resource is independently trying to maximize its value.

Additional system-wide savings in fuel and GHG reductions could occur by not operating other resources, such as combined cycle plants, at their less efficient part load, or possibly not operating them at all.

Reduced water usage. Reduced gas turbine run time, reduces the amount of water used for cooling and spray water process.

Managing air permits and air quality restriction. Hybrid systems can be better utilized under air quality restrictions by limiting the number of run hours or limiting the numbers of starts in line with air permits.

Grid Resiliency Benefits

Extreme weather events are occurring more frequently, while recognition of methodologies and technologies for addressing the consequences these events have not kept pace. There is a need to understand events that can simultaneously impact multiple generating units and to develop methodologies and technologies like Hybrid GT+BESS systems with which to mitigate their impacts on resource adequacy.

The electric industry systematically understates the probability and depth of many high impact common mode events. Extreme weather events are rising in frequency, intensity, geographic scope, and duration, the impact of weather is non-linear and rising much faster than frequency, a ten-year historical calculation of extreme event probability understates the likelihood of an extreme event in a changing climate.

An analysis of current reporting, resource adequacy metrics, and supply planning highlights the fact that the metrics used to measure resource adequacy are themselves inadequate in that Loss of Load Expectation (LOLE) and Effective Load Carrying Capability (ELCC) are measures of system capacity that often do not account for common mode events, and do not measure the depth, breadth or duration of outages or their economic impact.

ELCC calculations generally do not consider weather correlated deviations from standard profiles for variable energy resource (VER) output that might result in large fleet-wide variations in the output of both existing resources and incremental units. The availability and output of renewable sources being correlated with weather requires other resources to rapidly respond to significant changes in renewable energy production. Hybrid GT+BESS provided rapid response to loss of renewable energy production with the ability to provide unlimited duration energy production relative to stand-alone battery energy storage.

In addition the rising trend in disruptive events and common mode outages, the traditional approaches to ensure resource adequacy need to evolve and assess hybrid technologies that can enhance resource adequacy and extended operational capacity beyond the limits of standalone battery back-up to variable energy resources (VER) like wind and solar. In a world evolving toward renewable resources with increased variability, the role of technologies that can respond to this variability, i.e., natural gas with hybridized storage, are critical enablers. Hybrid GT+BESS systems address a critical gap in current approaches that do not focus on the correlated impact on multiple resources of common mode events, often weather-related, that can cause significant disruptions in supply.

Barriers to Hybrid System Deployment

Although there have been several Hybrid GT+BESS systems deployed and participating in wholesale electricity markets, there still exist barriers for broader deployment. Some of the barriers also exist for other hybrid systems and standalone energy storage, while others are unique to hybrid gas plus storage.

Valuation

Although the value streams of Hybrid GT+BESS systems have been detailed in previous sections, there remain gaps in quantifying some benefits or accurately modeling how the systems would be dispatched. Efficiency and heat rate curves for the technology's operating range need to be accounted for appropriately in the dispatch optimization. Additionally, priorities and objectives need to be

clearly defined. A system optimizing plant dispatch based on plant objectives may have different battery sizing and operational profiles from a system optimized for grid needs. This will impact capital and operating costs, which also need to be better understood.

Valuation is also a challenge is some competitive utility solicitations. If procurements are not structured to take into account the specific benefits of Hybrid GT+BESS systems, the systems may not appear competitive with other hybrids or standalone systems. As with other new technology entrants, to fully recognize the total system value of the hybrid system, detailed system-wide production cost modeling or market management system modeling may be required to account for specific hybrid plant benefits. Additionally, some solicitations specifically do not allow bidders to integrate and hybridize storage into their existing GT units.

Technology Integration

Implementation experience of Hybrid GT+BESS systems is limited relative to other traditional grid assets. This can add soft costs and may introduce new operational risk to the plant.

Controls of the hybrid system are a key element in realizing the full system value. Lack of sophisticated controls can result in less than optimal dispatch of the hybrid system, accelerated battery degradation, or increased operating costs. Through commissioning of the new control system should not only verify the operation of the two assets working together, but that there is no impact to the gas turbines normal operation.

Cyber security is another potential integration challenge. Many battery energy storage providers require remote access to the battery for warranty or performance guarantee contracts. Gas turbine plants may restrict remote access by third parties or require additional security measures which should be established upfront.

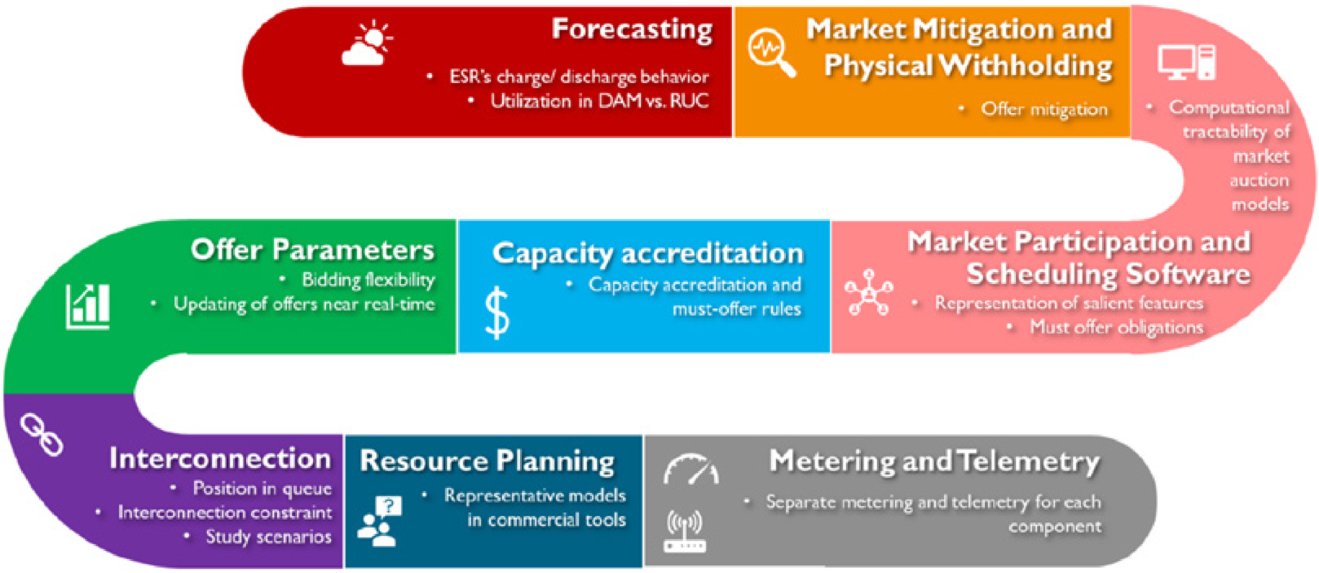
System safety is another consideration as the site design and operations must be adapted to a new set of risks and failure modes that may impact existing systems and operational approaches. Batteries present fire and explosion hazards that should be addressed at the plant level through proper engineering controls, procedures, and protective equipment. Care should be taken to adequately review and integrate the battery into the safety framework of the gas turbine site to ensure there are no compounding or confounding effects at the full system level of the integrated hybrid plant. With the rapid deployment of standalone and solar plus storage systems, many leading practices are being developed that apply to Hybrid GT+BESS systems, but additional battery testing and data is needed to better characterize system behavior under various abnormal conditions.

Market Integration

Recent regulations, namely FERC Order 841, have required ISO/RTO market designs be updated to accommodate standalone energy storage. While hybrid facilities were largely considered to be out of scope of FERC Order 841, the challenges identified in Order 841 for standalone energy storage resources also apply to hybrid resources. In 2020, FERC held a technical conference and invited post-conference comments on hybrid resources to discuss similar issues for hybrids including interconnection, market operation, and resource adequacy. In January 2021, FERC issued an order directing ISO/RTO to report out on current practices and update on ongoing reform efforts related to hybrid resource terminology, interconnection, market participation, and capacity valuation.

EPRI reports *Electricity Market Integration of Energy Storage and Hybrid Storage-Plus-Renewables Technologies 2019 Update* (3002016759) and *2020 Electricity Market Design Changes and ISO/RTO Updates* (3002019675) lay out the technical challenges to integrating hybrid plants into bulk electricity markets (see Figure 3). This section summarized the aspects of those reports that are applicable to hybrid gas turbine plus battery plants.

Forecasting. Forecasting challenges for hybrid gas turbine and storage facilities are less significant than hybrids with renewables. However, energy storage can be challenging to forecast as it must include both the charge and discharge behavior. Storage state of charge (SOC) forecast management may not be an issue if the ISOs/RTOs go with the single resource option and allow the asset owners to manage their own SOC. However, it may still be important to track the SOC to ensure the dispatch schedule is feasible for energy and ancillary services, especially in real time. Since the hybrid resource owner does not have the information of the rest of the system but must provide offers in advance, and without the RTO/ISO knowing the full capability and constraints of each technology across a multi-temporal horizon, it is possible that the resource can be scheduled sub-optimally.



Source: 3002016759.

Figure 3. Technical Challenges to Integrating Hybrid Facilities into Wholesale Electricity Markets

Market Mitigation and Withholding. Market power mitigation rules are well defined for gas turbines and other conventional resources. However, the industry is still in the process of developing the associated rules for energy-limited resources, such as battery energy storage. A hybrid as a single resource may be able to operate under existing rules, but those would not reflect the marginal cost and opportunity cost of the battery.

Market Participation and Scheduling Software. Hybrids may need appropriate representation of their unique physical and operating characteristics. Currently dedicated participation models for hybrid resources that appropriately account for their unique characteristics are at their infancy. They may fit under multiple market model configurations, e.g. CAISO Generator or Non-Generator, see Figures 4 and 5. As illustrated in Figure 4 and Figured 5, integrating energy storage with existing gas turbine units allows for:

- Larger operating ranges (even negative where applicable)
- Ramping speeds two to three time that of existing thermal units.

This larger range and faster speed means that a single hybrid resource can provide the net load following of multiple standard units.

Capacity Accreditation. Capacity accreditation methods and tools for hybrid resources are not well-defined and new rules may be needed, and whether the capacity credit of a hybrid gas turbine and storage are the same or more as the sum of the contribution of each technology. It is unclear how must-offer rules will be set for hybrid resources since storage rules are still being developed. This may depend on the market participation model being used.

Offer Parameters. There is a benefit to enhancing bidding flexibility (e.g. allow resources to update their bids/offers near real-time) and define operating parameters. For standalone energy storage, FERC Order 841 lists a set of 13 parameters to be provided, some of which may also apply to hybrid resources.

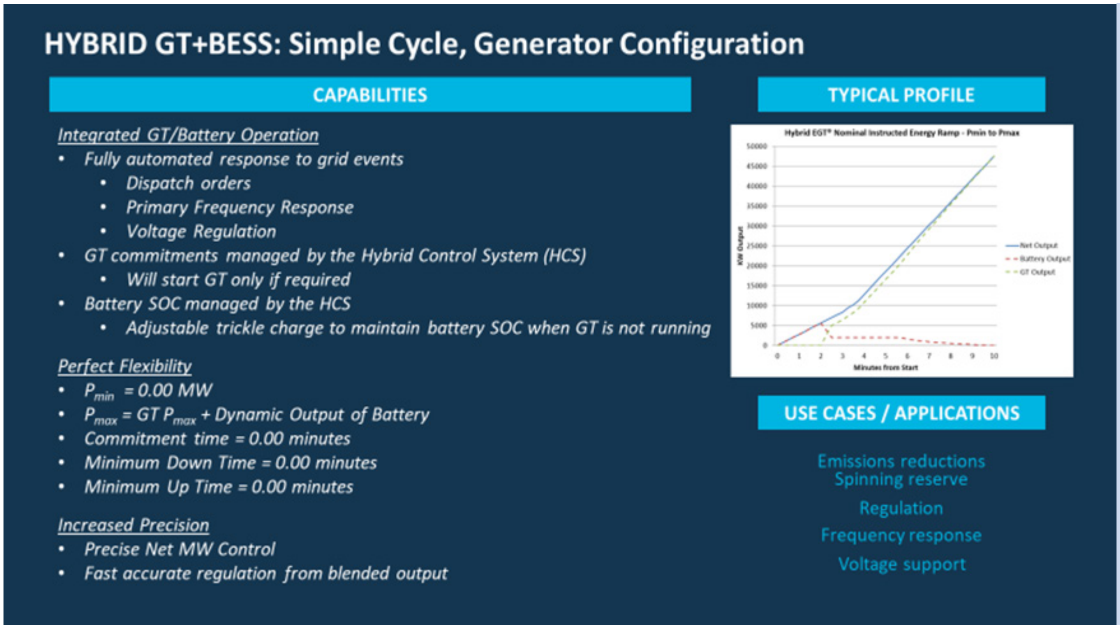
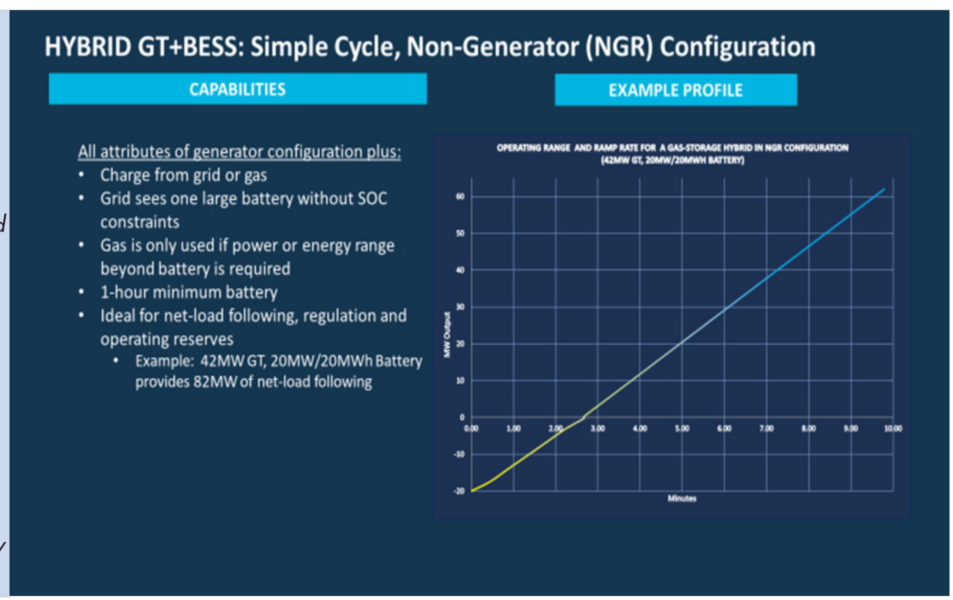


Figure 4. Hybrid GT+BESS: Simple Cycle Generator Model - Integrating gas turbines with energy storage can provide a fully automated generator that can ensure that grid events are immediately and accurately responded to while minimizing any fuel burn. This hybrid integration provides the perfect flexibility that traditional peakers lack, allowing the generator to come and go anywhere form zero to full load without constraints. This hybrid integration also provides for higher precision and increased ramp rates. Copyright permission granted to EPRI by Wellhead Power Solutions, LLC.

Figure 5. Hybrid GT+BESS: Simple Cycle Non-Generator (NGR) Model - By modeling the hybrid as a non-generator, grid operators will see the hybrid as a storage device with a portion of its output firmed by a secondary fuel source (natural gas or a renewable equivalent in this example). The generation porition of this integration retains all of the flexibility, precision and automation of the hybrid generator, but as a non-generator, this resource will primarily charge its storage from the grid. There is an overlap form zero MW to battery Pmax where the hybrid control system may respond with either stored energy, gas generation, or a blend. As with the generator operation the hybrid automation will immediately and accurately responded to any grid event while minimizing the fuel burn. This primary use case for a gas-hybrid in a non-generator configuration is intra-hour net-load following where the gas is used to cover unforeseen charging constraints. Copyright permission granted to EPRI by Wellhead Power Solutions, LLC.



Interconnection. FERC Order 845 and 845-A revise interconnection provisions for hybrid systems. FERC Order 845 aims to accelerate project timelines and decrease costs. FERC Order 845-A revised rules for pro forma Large Generator Interconnection Procedures (LGIP) and agreement (LGIA) to allow interconnection applicants below the combined generator and storage system nameplate capacity for technical review purposes.[3] Rather, the interconnection customer may propose control technologies to request service below the generating facility's maximum capacity. FERC Order 845-A also enables generation owners to add energy storage to an existing generation facility, and if the generation owner has surplus interconnection capacity, it can request a fast track interconnection process to utilize the surplus without re-entering the interconnection queue. As ISO/RTOs implement new interconnection processes, a few challenges remain. There is not consistent methodology or assumption for interconnection studies across ISO/RTOs, which may impact need for network upgrades, eligibility for fast track process, or need to re-enter interconnection queue. Also, some ISO/RTOs require separate interconnection agreements for each component, even if the hybrid is operated as a single resource.

Resource Planning. There is a lack of standard representative models for hybrid facilities in planning tools. A 2020 review of resource plans found hybrids are primarily being added exogenously into utility planning, rather than being the result of a capacity expansion model outcome.[4] Although hybrids are not yet being selected through planning tools in most of the plans reviewed, hybrids are being submitted into ISO interconnection queues and selected in utility procurement (mostly solar plus storage). As further model development takes place, there may be more endogenous selection of hybrids by resource planners.

Metering and Telemetry. There is no industry consensus on whether separate metering and telemetry is needed for each resource of the hybrid system.

Examples of How Technical Challenges are Being Addressed

In July 2020, FERC held a technical conference on hybrid resources to discuss technical and market challenges. Several ISO/RTOs report on the current status in updating market rules. This section includes excerpts from *Electricity Market Integration of Energy Storage and Hybrid Storage Plus Renewables Technologies, 2020 Market Design Changes and ISO/RTO Updates* (EPRI 3002019675).

Interconnection

FERC accepted MISO's hybrid tariff filing in April 2019. MISO has also developed preliminary interconnection study practices and dispatch assumptions for hybrids after numerous stakeholder discussions but intends to further improve the interconnection process in the future as the industry begins to gain more experience with these newer technologies. The interconnection process to add storage to an existing generation resource or an existing interconnection requests will remain as is in MISO, i.e., to enter the interconnection queue cycle with a new storage request. MISO plans to use the hybrid resource dispatch assumptions in its interconnection studies. If charging from the grid is part of the request, then MISO plans to also study a charging scenario in addition to discharging. Another option is to add storage to an existing resource without increasing the existing interconnection service is for the hybrid to go through the surplus interconnection process (much faster timeline since there is no need to go through the queue if there is no material modification).

CAISO permits energy storage to apply through its existing generator interconnection request process that is accepted annually in a cluster queue, or by pairing with an existing technology and utilizing the modification process (disallows increase in customer's net MWs at the POI, includes performing both short-circuit duty and charging evaluation) included in its Tariff and generator interconnection agreements.

Market Design

Table 1 below summarizes ISO/RTO market design proposals under FERC jurisdiction. Most entities are proposing two separate participation models: Co-located (separate resources) and hybrid (single resource). This table provides a summary on hybrid resource design proposals relevant to Hybrid GT+BESS systems.

[3] FERC, op. cit., notes 6 and 7.

[4] *Energy Storage in Resource Planning in the United States: 2020 Survey of Recent Results and Methods* (3002019109).

Table 1. ISO/RTO Market Design Proposals under FERC Jurisdiction and ERCOT

Market Design Aspect	NYISO	PJM	SPP	ISO-NE	MISO	CAISO	ERCOT
Participation Model	No option to participate as a single resource.	GT+ BESS being considered in Phase II.	MSRs	Settlement Only Generator, CSF	Generating Resource, or SER Type II/ESR	Generator or Non-Generator mode	Under development
Ancillary Services (AS)	Reserves & Regulation (ESR); Voltage Support (ESR)	All settlements & AS measurements at the POI (hybrid plant controller to ensure sum of components meets ISO instructions)		Allowed to provide reg as ATRR, CSF (allowed to provide reserves & reg)		Requires verification for availability and performance via telemetry.	(1) Regulation (2) Responsive Reserves, including Primary Frequency Response (governor droop) and Fast Frequency Response (15 cycles) (3) ECRS - ERCOT Contingency Reserve Service - 10 min start, off line or on line
Capacity Market	Existing mitigation rules will apply to individual components; CSR scheduling limit subject to existing physical withholding rules.	Proposal: ELCC reliability value for the entire hybrid class (12 classes: open loop and closed loop for solar and gen plus 4, 6 &10-hr ESRs), using a heuristic to allocate those MW among hybrids (based on size) including performance adjuster.		Configurations 3/Non-Intermittent FCM Resource & Configuration 4/Intermittent FCM Resource	Existing accreditation rules for individual components, e.g., 4 sustained hours. Owner determines split if IS limit exceeded.	CPUC proposed methodology (UCAP – post RAE initiative)	None - when system is short on reserves, ERCOT uses a scarcity Energy pricing mechanism to increase prices, up to $9000/MWH, encouraging investment in new capacity

ATRR: Alternative Technology Regulation Resource, CSF: Continuous Storage Facility, CSR: Co-located Storage Resource, ELCC: Effective Load Carrying Capability, ESR: Energy Storage Resource, FCM: Forward Capacity Market, MSR: Market Storage Resource, NGR: Non-generator Resource, RAE: Resource Adequacy Enhancements, SER: Storage Energy Resource, UCAP: Unforced Capacity

In areas with high levels of renewables, load following has evolved into a need for net-load following to cover the uncertainties of variable generation. Many ISO/RTOs have developed, and are working to enhance, market products to deliver the high ramp rates needed to manage the much larger uncertainty and volatility in net load. As an example, see the graphs below, Figures 6 and 7.

Specifically, the CAISO experience[1] in Enhanced Day Ahead Market products is relevant to other regions with growing renewables. To avoid the more costly emergency measures in Real Time, due to net load uncertainty and ramping differences, a Reliability Capacity and Imbalance Reserve product is being developed.

The magnitude of CAISO's net load uncertainty needs are staggering. For example, in one scenario studied, a P50 net load forecast of 18,500 MW has a 7,400 MW total variation.

Although increasing the required spinning reserve and regulation could handle the uncertainty, analysis has shown that ramp capability products result in much lower total production costs[2].

While standalone batteries have long been envisioned to provide this service, the state-of-charge limitations constrains their ability to provide this reliability on a continuous basis. The Hybrid GT+BESS provides the needed duration.

CAISO has introduced a co-located model and a hybrid model and believes that it should be capable of accommodating both models and adapting market rules as needed as these new technologies become more widespread. CAISO also stated the potential need to allow limited energy resources to bid in their opportunity costs to prevent a dispatch schedule that potentially impacts the economics and reliability of the solution in (later) high priced intervals.

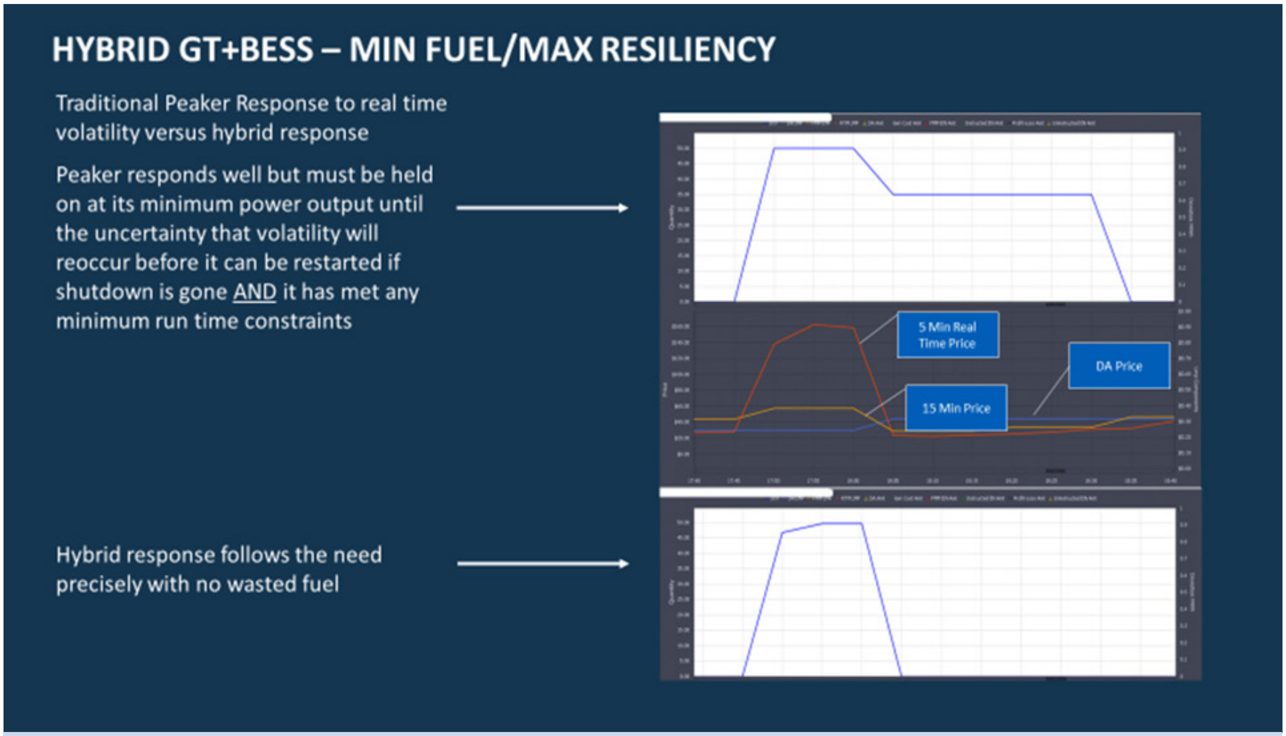


Figure 6. Hybrid GT+BESS Load Following - Hybrid response is more accurate, burns less fuel and does not displace more efficient resources. Copyright permission granted to EPRI by Wellhead Power Solutions, LLC.

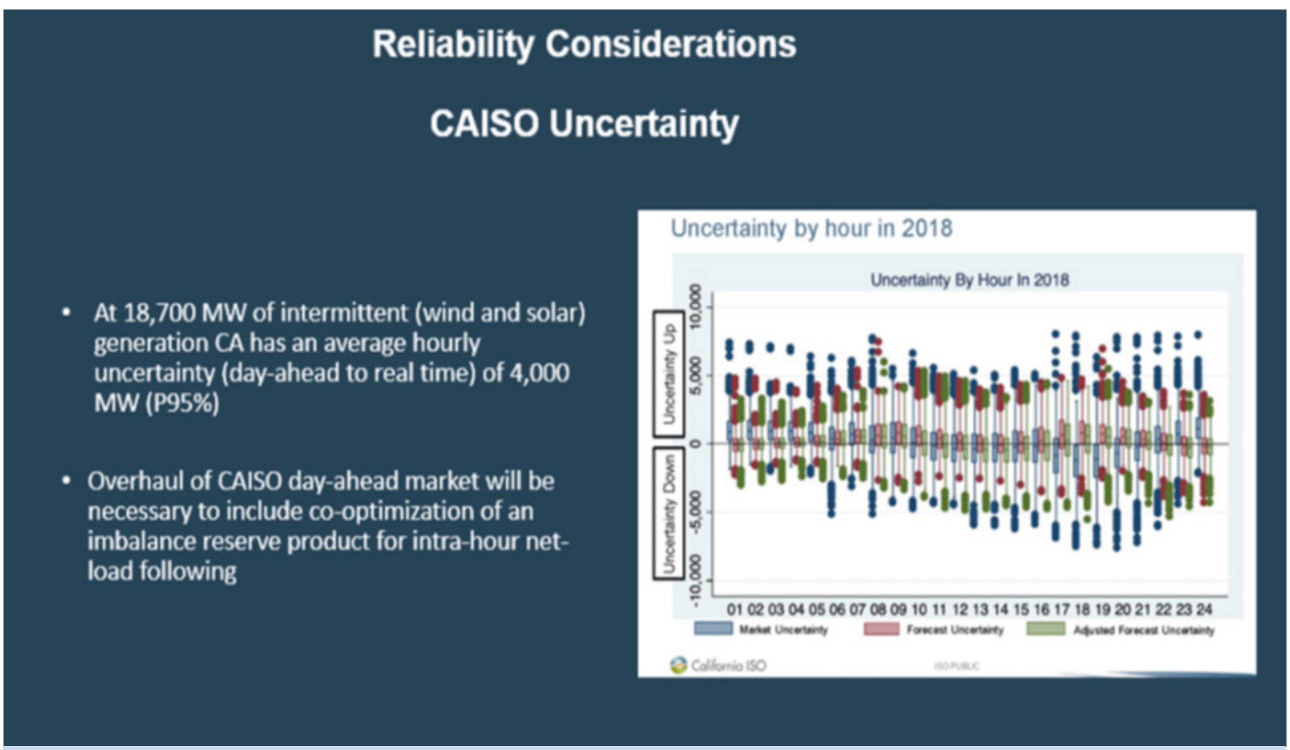


Figure 7. CAISO 2040 Net Load Uncertainty. Copyright permission granted to EPRI by CAISO.

Presently, few early hybrid resources are using the single resource model in CAISO; however, it is possible that new features can beneficially operate these resources to improve efficiency and reliability. Existing stakeholder processes are trying to address these barriers to accommodate improved models for hybrids with a target implementation date of fall 2021. Another challenge is market power mitigation for hybrids. Many ISOs are also looking at ways to allow for resources such as hybrids to make updates to their offer curves more frequently and closer to real-time to improve efficiency.

ERCOT, which is not under FERC jurisdiction, has discussed the use of quick start gas turbine plus battery storage to participate in the Responsive Reserve (RRS) Ancillary Services Market which bundles governor-type response with ten minute spinning reserve. As stated earlier, this is well suited for hybrid systems which allows for participation when the gas turbine is off-line. It offers the added flexibility to bring the turbine online for larger frequency deviations or longer duration needs.

Conclusions

There is an opportunity to improve grid performance and cost with hybrid gas turbine plus battery energy storage plants. This has been proven though several projects, but deployment is still low relative to solar plus storage hybrid and standalone storage systems. While there are some similarities between these different types of systems, gas turbine plus storage hybrids offer some distinct operational characteristics.

1. Ultra-fast response:
   - Ultra-fast start: Starting up from zero to the minimum environmental load in 250 ms
   - Improved tertiary reserve: All gas turbine power output range available from the first minute on a startup ramp.
   - The full range of gas turbine power available without limitation on minimum environmental load
   - The gas turbine provides an almost instantaneous reserve to load up
2. Improved flexibility:
   - Faster load ramp, up and down.
   - Improved black start capability.
   - Fast frequency response.
   - Improved turbine operating efficiency by avoiding load fluctuations
   - Extra capacity for peaking operation of the gas turbine
3. Emissions reduction:
   - Replacement of spinning reserve provided by online partial load GT with battery plus offline GT that can be brought online if needed.
   - Reduction of the number of gas turbine starts and therefore of emissions.
4. Improvement of auxiliary services and grid balancing:
   - Tertiary response from the first minute.
   - Faster secondary and primary reserve in case of necessary.
5. Improved grid stability for isolated systems:
   - Improved grid stability against gas turbine trips allowing to trip on the battery capacity rather than on zero generation.
   - Ultra-fast battery response in coordination with gas turbine rapid response to grid changes due to the volatility of renewable generation.
6. Optimization of the sizing of the required battery capacity
   - Reduction of the battery sizing and foot print requirements for their installation by coordinating their sizing with the existing gas turbine capacity.
   - Optimization of the recharge of the battery itself through the gas turbine by increasing the load point of the turbine and therefore its performance.
   - Coordinated control of both technologies allowing to have instantaneous battery power capacity and firm power capacity of the gas turbine power in a single asset with a single evacuation point without the need to increase the already existing connection points to the grid.
   - Reusing of existing assets without the need for new sites.

In many markets, the full value may not be realized until market rules reflect these characteristics. Hybridizing existing resources is an answer to the growing grid challenge - plenty of capacity, but not the right kind of capacity.

- Hybrids tune the gas-resource to blend with the inverter-based storage which means that they will contribute to small-signal sta-

bility. The ability to provide voltage support 24X7 helps prevent a weak grid.

- And, the performance capabilities provide high quality net-load firming, but without duration concerns.
- Gas is only used if and when needed but when it is needed the flexibility, speed and sustained production provide the grid with the support that it needs.
- In short Hybrid GT+BESS resources allow for Hybrid GT+BESS and any other variable energy resource-hybrids to do what they should be doing…supplying green energy when it is needed.
- Hybridizing GT with BESS is a practical scalable approach to building out additional grid flexibility as the system evolves.
- Hybrid GT+BESS technology is commercially available with significant and successful operating experience in the CAISO & AESO markets.

As the quest for reliability and flexibility is driving interest in Hybrid GT+BESS resources, their widespread integration could hinge on how they are defined and valued in wholesale electricity markets. Given the number of benefits of hybrid resources, ISOs, their stakeholders, and hybrid resource developers should proactively work to enhance ISO market rules and practices as applicable to facilitate the efficient entry and operation of Hybrid GT+BESS resources.

As the industry needs a better understanding of how the overall grid operation changes with new market rules, EPRI continues to research these topics to inform decision makers on hybrid implementation strategies.

Appendix A: Case Study–Southern California Edison's Center Hybrid Enhanced Gas Turbine

This appendix is a summary of *Bulk and Transmission Connected Energy Storage: Technology, Deployments, and Lessons Learned – 2018 Update*. EPRI, Palo Alto, CA: 3002013722.

Project Overview

The project installed the new 10 MW, 4.3 MWh lithium ion battery system and upgraded the existing 50 MW GE turbine, including integrated system controls.

Project Goals

- Achieve fast-ramp capability
- Achieve full range part-load flexibility
- Provide rapid response capability

Changes in Market Participation

- Participates as a non-generator resource (operates as generator and load; energy constrained)

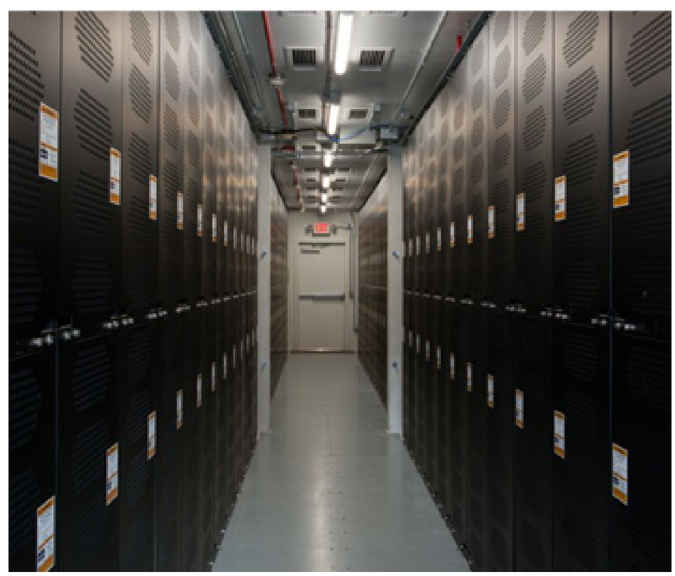


Photo Credit: Southern California Edison, https://energized.edison.com/.

Figure 8. Site photo of Southern California Edison's Center Hybrid Enhanced Gas Turbine (left) and interior view of the integrated gas turbine and battery storage system controls compartment.

- Increased participation in Ancillary Services
- New participation in additional, higher-value wholesale markets (Down Regulation, Frequency Regulation, and Spinning Reserve).
- More efficient Day-Ahead energy dispatch
- Ability to respond to short-term negative and positive price spikes in Real-Time

Environmental Benefits

- 60% reduction in GHG and criteria pollutant emissions due to a decrease in number of times the peaker plant needs to be restarted
- 40% reduction in water consumption due to emissions control system (saving 2 million gallons annually)

Appendix B: Status of Hybrid Gas Turbine plus Battery Energy Storage System

Hybrid gas plus storage systems have largely been deployed to enhance and complement the gas turbine plant's capabilities in providing ancillary services. The battery component is typically sized for shorter duration with the average duration of the batteries listed is 0.5 hours. The average battery to gas turbine ratio for power output is 0.2. In comparison, most standalone storage systems and solar plus storage systems are currently being deployed with longer durations, often four hours to meet resource adequacy requirements (participation in most ISO/RTO capacity markets or resource adequacy programs require a sustained response for four or more hours excepting ISO-NE). This indicates that the storage component of hybrid gas plus storage has differing primary objectives than a majority of other storage systems being deployed.

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Table 2. Table of Operational and Planned Hybrid Gas Turbine Plus Battery Energy Storage Systems (Hybrid GT+BESS)

Project Name	Country	BESS (MW)	BESS (MWh)	GT (MW)	Status	COD	Application
SCE LM6000 Hybrid EGT - Grapeland	US	10	4.2	50	Operational	2017	Spinning, Frequency Regulation, Load Following (Tertiary Balancing)
SCE LM6000 Hybrid EGT - Center	US	10	4.2	50	Operational	2017	Spinning, Frequency Regulation, Load Following (Tertiary Balancing)
Pilbbara region of Western Australia*	Aus	30	11.4	178	Operational	2018	Ancillary Services
Stanton Energy Reliability Center, LLC	US	20	10	98	Operational	2020	Ancillary Services
Perryville Power Station* Blackstart BESS	US	7.4	6.6	150	Operational	2020	Black Start
Fortescue Metals Group's Chichester* mining hub	Aus	35	11	145	Announced	2021	Firming / Ramp Control
ENMAX, Crossfield Energy Center	Alberta, CA	10	4.7	50	Operational	2021	Ancillary Services
Fresno Energy	US	15	15	50	Under Construction	2021	Ancillary Services/Net-load following

* Unknown If Hybrid GT+BESS or Co-Located BESS

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Program 217: Gas Turbine Advanced Components and Technologies
Program 39: Transmission Operations

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